TWA FLIGHT 800
1/4-SCALE CENTER WING TANK JET A EXPLOSIONS

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ABSTRACT

Applied Research Associates, Inc. (ARA) and the California Institute of Technology (Caltech) are key members of the team of experts conducting research for the National Transportation Safety Board (NTSB) in the investigation of the July 1996 explosion of TWA Flight 800. ARA and Caltech conducted 30 (1/4-scale) tests of the Center Wing Tank (CWT) during the past year. A 1/4-scale model of the large center fuel tank assembly, thought to be the source of the explosion, was constructed and instrumented for the experimental tests. As an "empty" CWT fuel tank (747-100) contains approximately 55 gallons of fuel, the fuel vapors generated during ground and flight operations may be susceptible to ignition sources located within the tank structure. The vapor ignition sensitivity would be enhanced due to external heating caused by the environmental control units which are located beneath the CWT structure. This vaporized fuel could be ignited by a suitable ignition source resulting in a fuel-air deflagration or detonation. ARA and Caltech conducted the 30 tests at ARA's Rocky Mountain Division's test site located Southeast of Denver. The tests were designed to provide controllable surrogate vapor mixtures and Jet A liquid fuel to understand flame combustion phenomenology and its effect on the scale tank pressures and temperature across the various fuel tank compartments. The explosive effects and internal partition response were documented by high-speed and SVHS video cameras. The ignition source locations were varied to replicate possible ignition sources on Flight 800. The instrumentation suite measured the quasi-static pressure, temperature, flame speed, and partition movement. Special photography was employed to document the combustion front and flame propagation through the tank compartments. Data analysis from this test series is on-going with results expected within the next year. The results of this program may provide insight into the Flight 800 event and may suggest how fuel tank deflagrations/explosions might be prevented in the future.

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INTRODUCTION

The NTSB has been conducting research into the possible causes of the TWA Flight 800 accident. One potential source of the explosion, which caused structural failure of the 747-100, is the CWT fuel compartment. The NTSB requested ARA, under the technical direction of Caltech, to investigate the effects of simulated fuel vapors and Jet A liquid deflagrations/detonations. To accomplish these goals, a 1/4-scale engineering model of the CWT was constructed by Caltech. This structure was approximately 5 feet by 5 feet by 1.5 foot which is one-quarter the size of the actual 747-100 CWT. This structure replicated the full size fuel tank's compartments, passageways, and vent tubes to the atmosphere. The 1/4-scale tank structure allowed the study of the flame fronts, combustion pressures and temperatures, and reaction of the tank partitions subjected to the combustion pressures. Structural effects of the beams or spars were not studied in this program. The surrogate fuel vapors were selected to provide the same combustion properties as the Jet A had at event altitude and temperature.

ARA (teamed with Caltech) was requested by the NTSB to provide the instrumentation and perform the experimental tests at the ARA test site located Southeast of Denver, Colorado. Thirty tests were conducted in the 1/4-scale CWT structure to investigate fuel combustion phenomenology, the results of which could provide guidance to the NTSB in the on-going investigation. The ARA/Caltech team provided the test site, instrumentation, and photoinstrumentation systems necessary to document the combustion properties for the various test scenarios. Pressure transducers (dynamic and quasi-static) and thermocouples were used to document the pressure and temperature profiles versus time for each test configuration. Light sensors were used to detect flame front arrival and motion sensors were positioned at multiple points on each of the failing/weak partitions to determine partition movement. Digital and back-up analog recorders were used to capture the sensor signatures for "quick look" evaluations and for later time final analysis and reporting purposes.

PROGRAM EFFORTS

This program was designed to examine various ignition locations, vapor concentrations, effect of a Jet A liquid layer, and the failure of partitions within the tank. The experimental program consisted of 30 tests which included four major test configurations. The first test series included vapor tests with all-strong partitions and no venting, without partitions, and with partial partition placement using the standard surrogate fuel vapor mixture for baseline and validation tests. The second series also used an all-strong configuration with the standard fuel vapor (with liquid Jet A added for one test) with full partition placement and differing ignition source locations. The third series consisted of a mixture of partition configurations from partially weak, all-strong and combinations of weak and strong. The fuel vapors consisted of the standard mix, standard with a layer of Jet A liquid on the bottom of the tank (to simulate an "empty" 747-100 CWT), and with two types of lower vapor concentrations. The fourth test series was conducted to document the effects of the "cargo bay" volume on the combustion process.

TEST SETUP AND DESCRIPTION

TEST FACILITY

The tests were conducted on ARA's test facility located 35 miles Southeast of Denver, Colorado. This site was remote from the population base and had the infrastructure requirements to support the 1/4-scale experiments. Figure 1 shows a plan view of this test site with the layout of the major components required to implement the program effort.

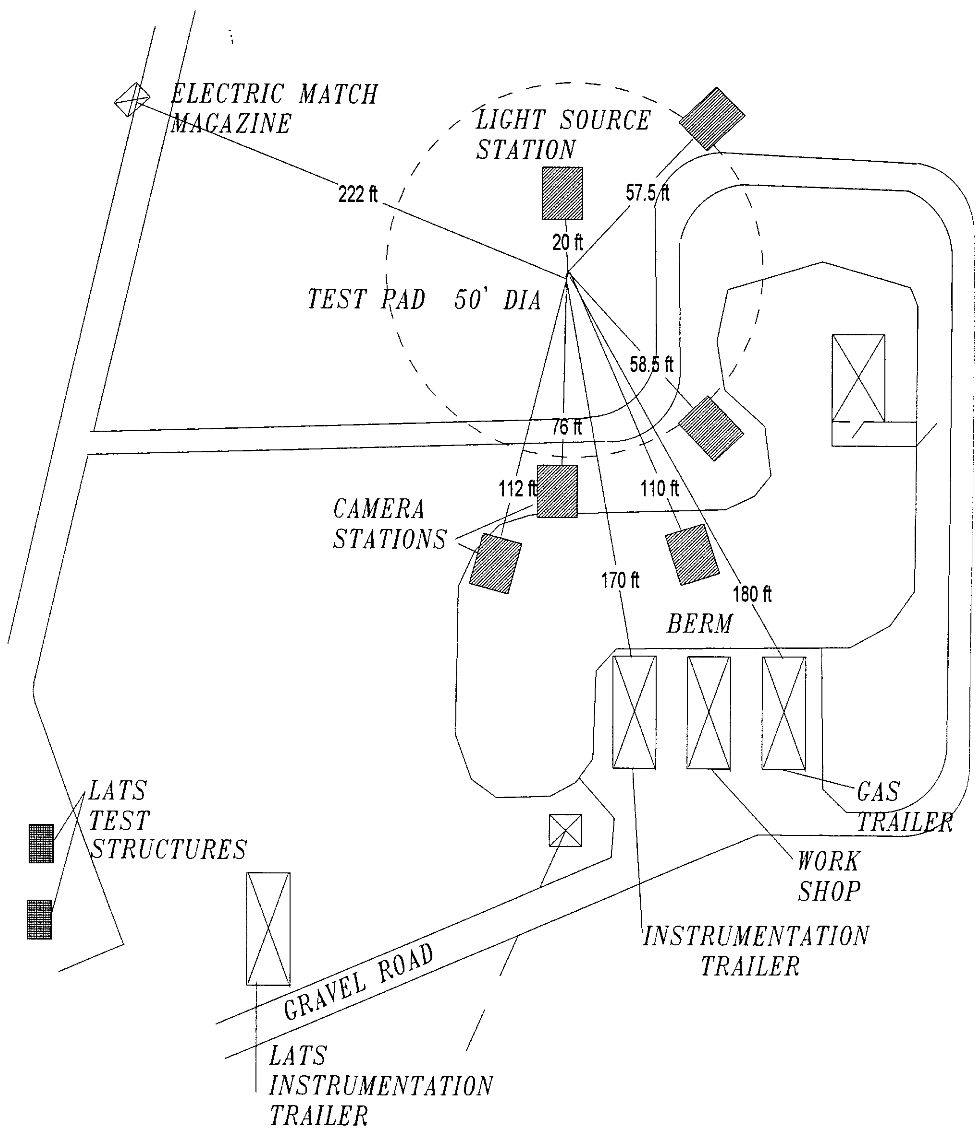

Figure 1. ARA Test Site Layout

Figure 2 shows the 1/4-scale test fixture in position. The fixture was set on, and anchored to, concrete pads which allowed leveling of the tank pre-test and prevented tank movement during the combustion event. Figure 3 shows an overview of the 1/4-scale fixture and surrounding instrumentation housings.

Figure 2. 1/4-Scale Test Fixture in Test Position

Figure 3. Overview of 1/4-Scale Structure and Test Site

INSTRUMENTATION

The electronic measurement channels used for the 1/4-scale test program consisted of 14 channels of temperature, 7 channels of quasi-static pressure, 10 channels of dynamic pressure (located within the tank), 3 channels of dynamic pressure (outside the tank), 18 channels of motion detectors, and 7 channels of photodetectors. A brief review of the function of each type of measurement channel is presented below:

- **Temperature ---** Two Type K, temperature probes were used in each compartment to provide the combustion temperature versus time information.

- **Quasi-Static Pressure ---** These pressure transducers were used to measure the quasi-static pressure of all compartments. To eliminate thermal effects from the combustion temperatures they were fitted with thermal protection and debris shields to assure integrity of test-to-test data.

- **Dynamic Pressure ---** The in-tank dynamic pressure transducers were used to measure shock pressures of the combustion front. These transducers were thermally protected by a grease layer which afforded early time protection. The dynamic pressure transducers located outside the tank were used for the failing partition tests to measure the shock front after ejection of the partitions.

- **Partition Motion Detectors ---** Break-switch sensors were positioned at several locations on each partition to measure the exact time of partition movement relative to the flame front and pressure build-up relative to event time zero.

- **Flame Front Photo Detectors ---** The photo detectors were positioned within each compartment to monitor flame luminosity as the flame front progressed throughout the various compartments.

Signal conditioning provided the interface from the suite of sensors to the recording systems. The signal conditioning included excitation, amplification, and filtering (where applicable). The recording systems were comprised of 83 discrete channels. Twenty-six channels of high-speed 12-bit digitizers capable of sampling at 200 nanoseconds per point, with 512 Kbytes of memory per channel, were used for the high-speed recording requirements. The slower recording requirements were satisfied by using 64-channel (not all channels used), 12-bit, digitizing systems which provided up to 10 seconds of recording at the 1.0 millisecond per point sampling rate. These recording systems were controlled by bench top computers using LabView software which was modified by ARA personnel to include setup configuration tables, selection of digitizing rates, memory allocation and other menu-based macros which controlled the recording system's operational parameters. Quick look field plots of all channels were provided by laser-jet printers within 15 minutes after the test event occurred. Back-up data recording was provided by two Honeywell 101 Wide Band Group II instrumentation grade magnetic tape recorders. These recorders provided a frequency response from DC to 500 kHz.

Weather recording was accomplished by using a 6-channel weather station which provided continuous records of the outside/inside temperature, barometric pressure, humidity, and wind speed and direction. Figure 4 depicts the block diagram of the instrumentation system.

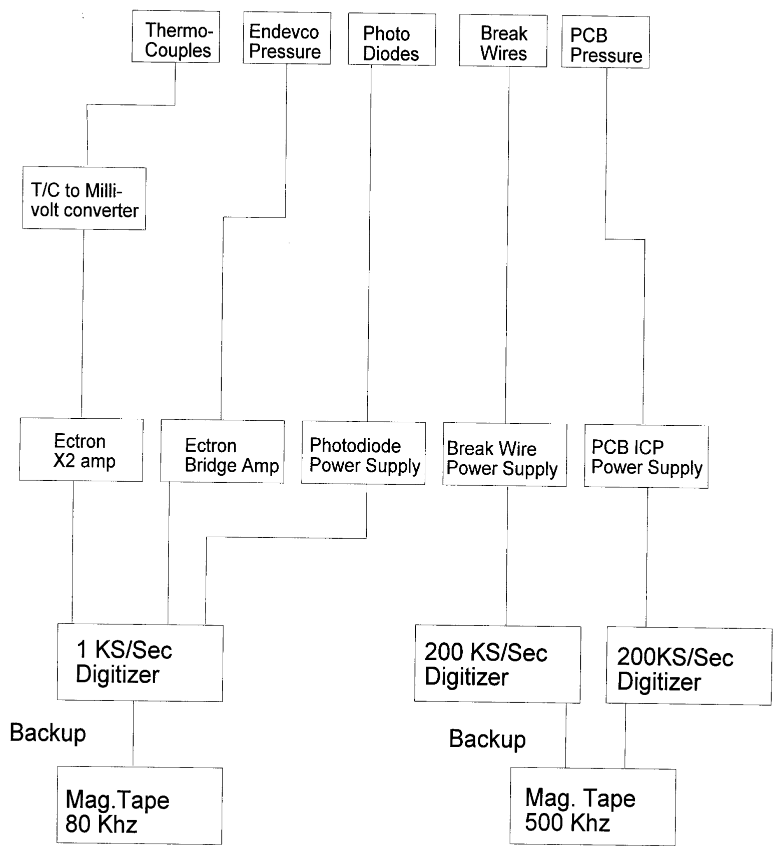

Figure 4. Block Diagram of the Instrumentation System

- **Photoinstrumentation ---** Test photography consisted of 18 cameras providing film and video documentation of the 1/4-scale tests. Each camera had a unique function that provided data and documentation of specific aspects of the experiment. A brief description of this photographic suite is provided below:

  High-Speed Photography --- Seven high-speed cameras operating at 400 frames per second were used to provide combustion and overview photography. Two of the cameras provided overviews of the fixture behavior during the event and provided information on partition failure and the fuel venting (fireball) process when partition(s) failure occurred. Four cameras were used to document flame propagation and fuel lofting inside the fuel tank. ARA designed a special lighting system (pseudo-Schlieren) for the photography of the combustion process through the tank's Lexan windows. The pseudo-Schlieren system provided a means of achieving the optical resolution necessary for detecting the small gradient changes in gas front density inherent to fuel air combustion processes. Figure 5 shows the

combustion photography light sources as viewed from behind the tank and Figure 6 shows the high-speed and video cameras used to record the images.

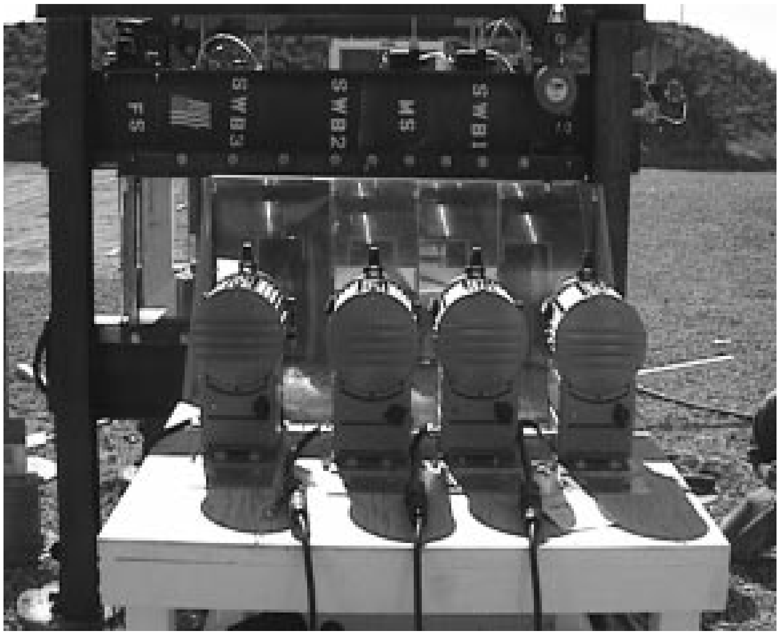

Figure 5. Light Source Configuration for Combustion Photography

Figure 6. Combustion Photography Camera Station

Video Cameras --- Three SVHS video cameras recorded the test area with different fields of view, and two cameras provided real time recording of the combustion process. The effective shutter speed of these cameras was 1/1000 of a second. In addition to providing event dynamic characteristics, they provided

safety information prior to personnel re-entering the 1/4-scale test fixture area. The combustion video cameras viewed the event through beam splitters inserted into the optical path of the high-speed cameras which provided immediate access to information regarding the test.

70 mm Photography --- A 70 mm motion picture camera, operating at 20 frames per second, with a 350-microsecond exposure time per frame, was used to provide very high resolution color images for selected tests.

35 mm Photography --- Two Single Lens Reflex cameras, fitted with motor drives (operating at 4 and 8 Fr/sec) were used to document the deflagration/detonations. Each camera was timed to event time zero to capture the early-time combustion and later-time fireball and fuel burning. Two additional cameras (a 35 mm camera and a digital camera) were used for normal pre- and post-event documentation for each test in the series, and for rapid transmission of test event data to other team members of this investigation.

TEST DATA

DATA REDUCTION AND ANALYSIS

The electronic sensor information was processed by LabView and DPlot analysis and plotting routines. Quick look field plots of test data were made to assess the performance of the sensors and to allow quick field site decisions to be made on any required changes to the test series protocol. More detailed analysis was performed in the laboratory environment. Figure 7 and 8 show typical pressure and temperature time information gathered on this program effort.

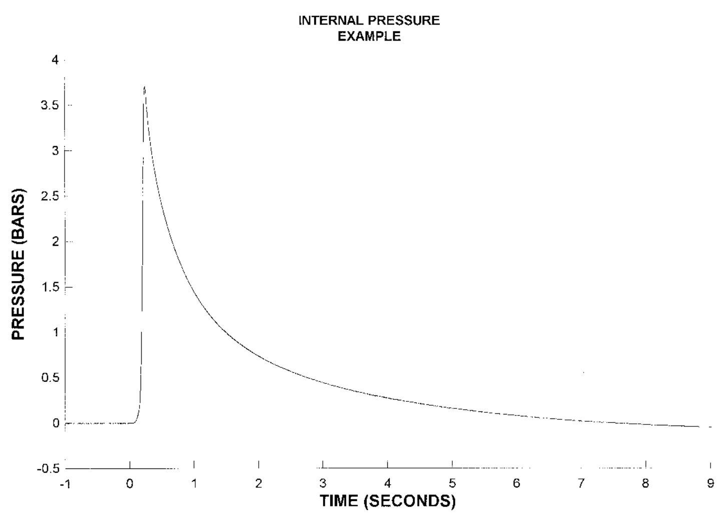

Figure 7. A Typical Pressure Time Plot (All Strong Configuration)

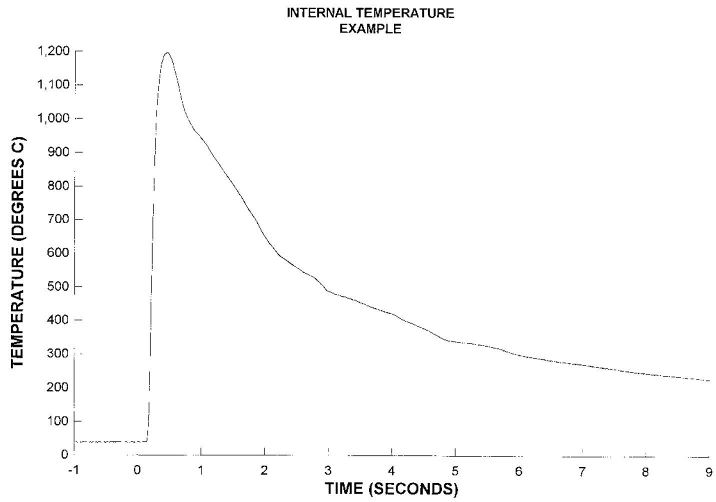

Figure 8. A Typical Temperature Time Plot (All Strong Configuration)

The photographic, emulsion-based data was edited and compiled for conversion to video format. As one of the main interests of this program was documentation of the flame propagation inside the tank compartments, considerable attention was given to providing the best visualization possible of the combustion camera records. Because each of the compartments were photographed with individual cameras, all four cameras needed to be compiled on one medium. After the film records were copied to video, each frame was digitized and stored on a computer hard drive. Using non-linear editing techniques, all of the video sequences were assembled on one video frame (comprised of the four images). Adjustments, such as slight differences in camera speeds, event timing, and slight variations in image size were made to achieve commonality for analysis purposes. The assembled video composite portrays the entire test fixture and compartments of combustion, as if one camera photographed all of the bays. Detailed combustion information could then be derived from viewing the flame propagation as it traveled from compartment to compartment.

Figures 9 and 10 show typical film records of a test with the surrogate fuel vapor with a Jet A liquid fuel layer on the bottom of the tank. Note the ejection of the weak partitions in Figure 9, and the extent and size of the fireball in Figure 10.

Figure 9.

Figure 10.

SUMMARY

The 30 tests were successfully conducted with high data returns. This test series has shown that, given an adequate ignition source, a fuel vapor/liquid Jet A mixture can propagate throughout the tank structure and cause failure of the partitions within the tank. Results (actual pressures and temperatures) of these tests will be released in the future. Test results may provide guidance for changes in design and procedures which could enhance aircraft safety in the future.

FUTURE EFFORTS

During the next year, additional tests will be conducted using Jet A vapor (instead of surrogate vapor) at simulated event altitude pressures and temperatures. These tests will provide additional information on the conditions and complexities of the effects of ignition location, vapor concentrations, effect of a Jet A liquid layer, and failure of the partitions within the 1/4-scale CWT structure.

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